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Techno-Economic Feasibility Analysis of a Microgrid in Downtown Cleveland, Ohio

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Executive Summary

Increasing the resiliency of the electrical utility system in a region has numerous benefits to the residents, companies, and public entities operating in that region ranging from improved safety to financial impacts. However, attracting political interest and capital for such a major infrastructure improvement project requires an expectation from the potential participants that the project will be technically possible and economically attractive for investors. Performing a feasibility study is an important first step to ensure that a project is worthy of pursuit from both a technical and economic viewpoint.

A Study Team was assembled by the Cleveland Foundation to evaluate the technical and economic feasibility of the creation of a microgrid within an area of downtown Cleveland, Cuyahoga County, Ohio (hereinafter sometimes referred to as “Cleveland uGrid”). The proposed microgrid would provide participants an increase in electrical system uptime to 99.999%, or less than 6 minutes of power loss per year, plus additional benefits in improved power quality and reduced costs for backup systems. The uGrid proposal is unique in its purpose and therefore its design. The purpose of developing the microgrid would be to provide for economic development through attracting new business investment in the delivery area. To accommodate this purpose, the proposed microgrid would be ‘in front of the meter’ as a rate and delivery option from the local municipal utility to multiple potential customers, unlike most microgrids today which are ‘behind the meter’ and for a single captive customer.

The Study Team reviewed existing microgrid systems and had extensive conversations with industry experts and leading providers of microgrid controls and associated equipment to determine technical feasibility. The Study Team also built an economic model from the vantage point of a potential private developer to understand and test the conditions under which the developer could construct and operate the microgrid to obtain an appropriate return on its investment.

The summary results of the techno-economic modelling and analysis for this specific microgrid project and study area are:

- Construction and operation of such a microgrid are complex, but technically feasible with commercially available technology and existing suppliers.
- The existing assets in the study area, specifically the existing and proposed thermal energy facilities (Cleveland Thermal) and the existing municipal utility (Cleveland Public Power), are critically important to economic success.
- Multiple entity arrangement options exist and selecting the right entity structure is important to minimize taxes and maximize opportunities for low cost financing.
- The proposed microgrid appears to be economically feasible, but will be highly sensitive to:
    - Customer rates
    - Successful and timely customer recruitment

- Availability of long term, competitive electrical power and natural gas prices
- Cost of capital / Interest rates
- Distribution costs from the municipal utility

Based upon the models developed, the Study Team has concluded that 99.999% (five-9) uptime can likely be delivered to end users for less than an average of 14 cents/kWh, which, based upon a related market evaluation prepared by the Study Team, appears to be a threshold price that would likely attract businesses that value resiliency. Indeed, based upon the models developed, it appears that a microgrid could potentially deliver five-9 power for 13 cents/kWh or lower to 50 customers with an average demand of 1 MW each, while returning 3% on investor capital in present value dollars after repaying all debt and interest at 5%.

I. Introduction

This study is one of four reports that form a microgrid planning evaluation for downtown Cleveland, Ohio undertaken by researchers at Cleveland State University and Case Western Reserve University (jointly, the "Study Team"), and underwritten by the Cleveland Foundation.[1] The evaluation has been undertaken in collaboration with Cuyahoga County and the City of Cleveland to determine the technical and economic feasibility of creating a microgrid within an area of downtown Cleveland, Ohio (hereinafter referred to as "Cleveland uGrid" or just "uGrid"). The other three reports look at the value of resiliency to end-users,[2] the potential interest of commercial end-users in microgrids as well as the economic impact that might accompany microgrid deployment,[3] and strategies and options for microgrid cyber-security.[4]

The uGrid Study Team looked at several attributes in selecting a location for evaluation. These included the following:

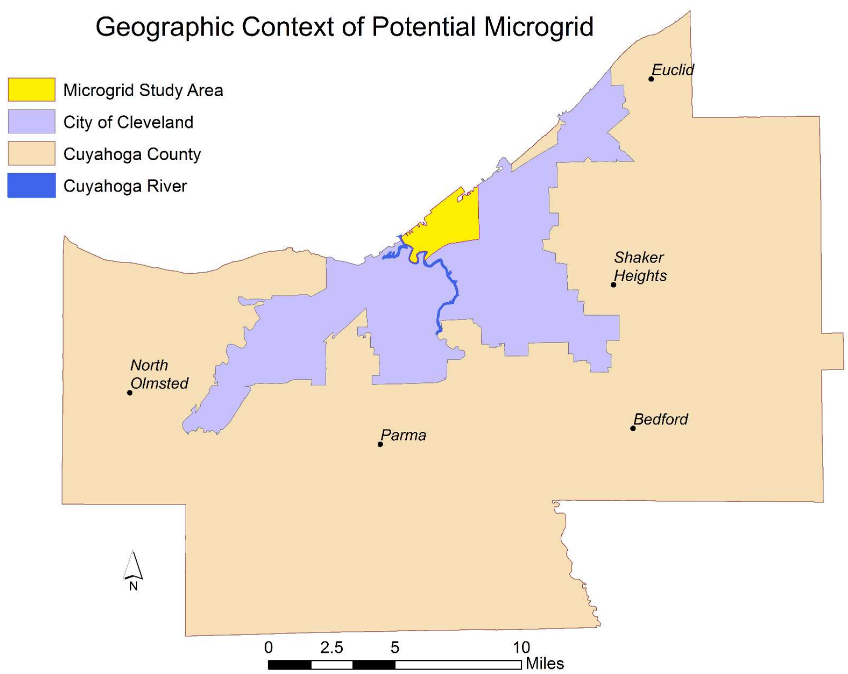
- Potential anchor tenants and institutions
- Ability to leverage existing infrastructure
- Existing loads vs. infrastructure capacity, and ability to grow either
- Economic relevance of areas
- Available land for new infrastructure and end users

[1] The Microgrid Cleveland Study Team consists of Cleveland State University's Energy Policy Center (Urban College), Case Western Reserve University's Great Lakes Energy Institute, Cuyahoga County and the City of Cleveland, and several consultants. The authors of this particular study are: Ali Ahmed of Green Strategies, LLC, and Andrew R. Thomas and Mark Henning of the Levin College of Urban Affairs at Cleveland State University.
[2] *See* Thomas, A. R., & Henning, M. (2017). "Valuing Resiliency from Microgrids: How End Users Can Estimate the Marginal Value of Resilient Power." *Urban Publications* (Levin College of Urban Affairs – Energy Policy Center). https://engagedscholarship.csuohio.edu/urban_facpub/1516/
[3] See Thomas, A. R., Henning, M., Date, K., & Simons, R. A. (2018). "The Economic and Fiscal Impact of a Microgrid in Downtown Cleveland, Ohio." *Urban Publications* (Levin College of Urban Affairs – Energy Policy Center). https://engagedscholarship.csuohio.edu/urban_enpolc/
[4] *See* Juhasz, J., & Shull, C. A. (2018). "Cuyahoga County Microgrid System Security and Resiliency Report." *Urban Publications* (Levin College of Urban Affairs – Energy Policy Center). https://engagedscholarship.csuohio.edu/urban_enpolc/

- Regulatory compatibility

Based upon a review of these considerations, uGrid Cle chose an area of downtown Cleveland for study. A map of the proposed microgrid location for is set forth below:

Figure 1. Proposed Downtown Cleveland Microgrid Location



This report focuses on the technical and financial aspects of implementing and operating a microgrid in the study area. A companion study that will be posted simultaneously herewith examines the potential market conditions of the proposed microgrid. While cyber and physical security of the microgrid will be addressed in detail in a third parallel report, costs for the design and installation of secure physical, information, and control systems have been included throughout in our model.

II. Technical Feasibility

The technical feasibility evaluation was completed in two parts. First, general information on existing microgrids and microgrid technology was collected and evaluated. Second, a high-level design for a potential microgrid for the study area was developed. This conceptual design included input from Cleveland Public Power, Middough[5], Cleveland Thermal, Schneider Electric,

[5] Founded in 1950 by William Vance Middough, Middough Inc. is a private, nationally ranked engineering, architectural, and management services company providing full-service from major projects to consulting for a range of requirements between small and global organizations.

Eaton Corporation, and other industry experts[6], as well as from the knowledge and experience of the Study Team. By creating a conceptual design that the Study Team and outside experts believed could be constructed and would operate successfully, technical feasibility was confirmed, with the understanding that an actual constructed system might differ in the details of the design.

Based on the research and the conceptual design, the Study Team determined that a microgrid in the study area would be feasible to construct and operate. The basis for this determination is set forth below.

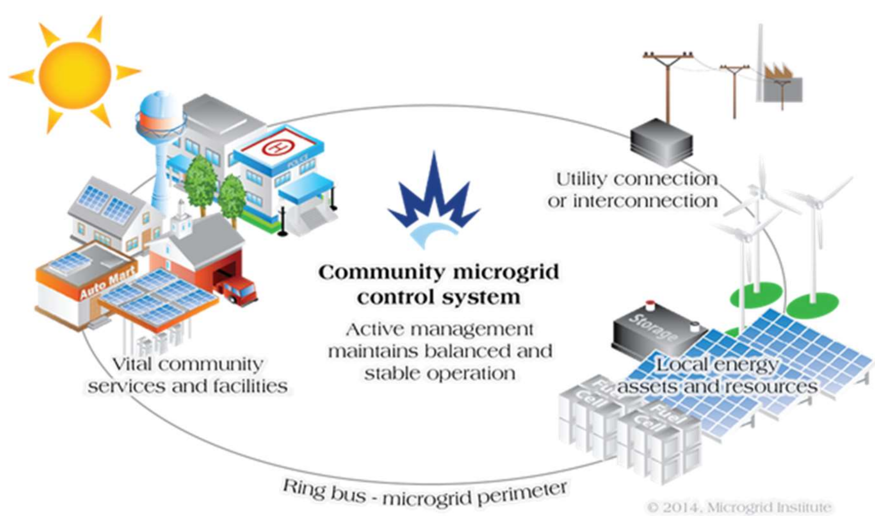
A. Definition of a Microgrid

A microgrid is a contained energy system capable of balancing captive supply and demand resources to maintain reliability. Microgrids have the following key elements and features:

- Defined by function, not size
- Incorporates multiple distributed technologies
- Maximizes reliability and efficiency
- Can include other utilities – steam, hot water, chilled water, network connectivity
- Can function in "islanded mode" disconnected from larger utility grid

A prototypical microgrid is pictured in Figure 2 below.[7]

Figure 2. Proposed Microgrid Generation by Source



[6] Cuyahoga County issued a Request for Information in the fall of 2017 seeking non-proprietary suggestions about microgrid control system design. The County received numerous responses to the RFI, all of which helped inform the model. However, it was clear from the responses that there are a number of ways to design the Cleveland uGrid. The Study Team leaves it to the eventual developer to establish its own ultimate design.

[7] From Microgrid Institute, http://www.microgridinstitute.org/about-microgrids.html

B. Survey of Existing Microgrids and Microgrid Technology

To assess feasibility the Study Team first undertook a literature search of existing microgrids and microgrid technology. Microgrids are commonly recognized by their incorporation of electrical storage devices into a distributed energy resource system.[8] The U.S. Department of Energy Global Energy Storage Database accordingly provides a useful estimate of the number of existing microgrids in the U.S. This regularly updated database listed 48 operational energy-storage projects with microgrid capability as of July 2018.[9] Additional microgrids were identified from case studies compiled by Lawrence Berkeley National Laboratory[10] and the Pace Energy and Climate Center.[11] The website *microgridknowledge.com*, which compiles news on developments in the microgrid industry, was also used to discover new projects. Altogether, the Study Team identified 78 currently operational microgrids in the United States.

The classification of these microgrids was based on two typologies set forth by Schneider Electric[12] and the Microgrid Institute.[13] First, microgrids were categorized according to the type(s) of entities served by the distributed energy system, for example whether they were commercial or industrial in nature, or whether they provided critical services to the community. Second, microgrids were classified by the scope of their coverage area, and included the following categories:

- Nanogrid, where power is provided to a single building;
- Campus microgrid, where power is provided to multiple buildings that are organizationally related, such as at a university;
- District energy microgrid, where power is provided to multiple organizationally unrelated facilities; and
- Community microgrid, which is synonymous with a utility microgrid that can provide power for an entire community, such as a remote village.

Table 1 presents a cross tabulation for the counts of current microgrids according to combinations of these two factors. The Study Team estimated a total capacity of around 1 GW

[8] *See* "Microgrid Definitions." *Microgrids at Berkeley Lab.* (n.d.). Accessed August 24, 2017, https://building-microgrid.lbl.gov/microgrid-definitions
[9] *See* "DOE Global Energy Storage Database." *U.S. Department of Energy*. (2017). Accessed August 11, 2017, www.energystorageexchange.org. *See*: https://www.energystorageexchange.org/ The DOE recognizes that this list is not exhaustive. *See id.*
[10] *See* "About Microgrids." *Microgrids at Berkeley Lab.* (n.d.). Accessed August 24, 2017, https://building-microgrid.lbl.gov/about-microgrids
[11] *See* "Microgrids & District Energy: Pathways to Sustainable Urban Development." *Pace Energy and Climate Center.* (2015.). Accessed August 24, 2017, https://digitalcommons.pace.edu/environmental/1/.
[12] *See* "Microgrids-at-Scale Based on Smartly-Connected Distributed Energy Resources." *Schneider Electric Microgrid Solutions.* (n.d.). Accessed August 20, 2017, http://www.michigan.gov/documents/mpsc/Microgrid_Solutions_2017_May_10_aah_pdf_568663_7.pdf
[13] *See* "About Microgrids." *The Microgrid Institute*. (2014). Accessed August 20, 2017, http://www.microgridinstitute.org/about-microgrids.html

for these microgrids based on the distributed energy resources (DER) forming their generational foundation.

Table 1. Number of Microgrids by End Use and Scope (as of July 2018)

Type of Entity Served	Scope of Microgrid				
	Campus	Community	District	Nanogrid	**Total**
Commercial	4	0	0	6	**10**
Commercial, industrial	2	0	0	0	**2**
Commercial, residential	0	0	4	0	**4**
Critical services	6	0	4	4	**14**
Education	13	0	0	4	**17**
Industrial	3	0	1	2	**6**
Military	14	0	0	0	**14**
Residential	3	0	0	1	**4**
Utility	0	7	0	0	**7**
Total	45	7	9	17	**78**

More than one third of existing microgrid deployments are found in either California or New York. The list of microgrids is likely to expand rapidly due to government programs aimed at microgrid development in these states. The State of New York, for example, has already distributed nearly $20 million to 83 communities across the state via the ongoing three-stage NY Prize Competition administered by the New York State Energy Research and Development Authority (NYSERDA) to support community grid planning and development.[14] Communities selected upon completion of the final stage—set to commence at the end 2018 with winners announced in late 2019—will receive upwards of $50 million per project through the State's NY Green Bank for actual build-out.[15]

As part of NY Prize, eleven communities were awarded competitive grants by NYSERDA to both conduct a $100,000 Stage 1 feasibility study and to issue a Stage 2 $1,000,000 design Request-for-Proposal (RFP) that included detailed project construction and operational proposals on microgrid development from third-party vendors.[16] The proposed microgrids for three of these eleven communities were somewhat similar to the prospective Cleveland microgrid in that they

[14] "Governor Cuomo Announces $11 Million Awarded for Community Microgrid Development Across New York." *NYSERDA*. (2017). https://www.nyserda.ny.gov/About/Newsroom/2017-Announcements/2017-03-23-Governor-Cuomo-Announces-11-Million-Awarded-for-Community-Microgrid-Development
[15] "NY Prize: Competition Structure." *NYSERDA. (n.d.).* https://www.nyserda.ny.gov/All-Programs/Programs/NY-Prize/Competition-Structure
[16] *Id.*

were predominantly powered by CHP and could be characterized as utility-scale[17] systems in terms of capacity.

Table 2 lists these three microgrids along with their DER capacity (not including storage), the percent of DER capacity from CHP, and the benefit-cost ratio resulting from a benefit cost analysis (BCA) that each community was required to perform as part of its Stage 1 feasibility study.[18] Note that the BCA is a different measurement than the economic model developed for the uGrid project—the BCA measures overall benefits to the community while the uGrid economic model evaluates the direct financial benefits for the microgrid operator. The BCA model that each community utilized assumed a 20-year operating period and a 7% discount rate, which is consistent with the U.S. Office of Management and Budget's current estimate of the opportunity cost of capital for private investments.[19] The basic BCA model weighs monetized benefits versus costs under normal operation conditions assuming no major power outages.

Table 2. Proposed Utility-scale Microgrids Primarily Powered by CHP in New York State

Community	Total DER Capacity in MW (not including storage)	Percent of DER capacity from CHP	BCA ratio under normal operations
East Bronx (Bronx)	29.0	82.7%	1.4
City of Albany (Empire State Plaza)	16.0	100.0%	1.1
Village of Rockville Centre	7.6	92.5%	4.85

As seen in Table 2, the three proposed microgrids had BCA ratios of greater than 1 under normal operating conditions. The Brookhaven National Laboratory, in its evaluation of the NY Prize feasibility studies where this BCA model was used by all participating communities, recommends that for microgrids, a BCA ratio greater than 1 should be considered profitable for potential investments.[20] The BCA ratios for the microgrids included in Table 2 indicate that even if there were no major power outages over the 20-year operating period, project benefits would exceed costs.

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[17] The Study Team considered 7 MW to be the threshold for classifying utility-scale capacity. For example, stories in the press about the recently approved Commonwealth Edison microgrid cluster in Chicago—with its slightly more than 7 MW of distributed energy resources—have described it as the "first utility-scale microgrid cluster in the nation." *See* "Special Alert: ComEd Wins Approval for Innovative Microgrid Cluster in Chicago." *Microgrid Knowledge*. (2018). https://microgridknowledge.com/microgrid-cluster-chicago-approved/

[18] *See* "NY Prize Feasibility Studies." *NYSERDA.* https://www.nyserda.ny.gov/All-Programs/Programs/NY-Prize/Feasibility-Studies

[19] *Id.*

[20] "Evaluation of New York Prize Stage 1 Feasibility Assessments (final report)." *Brookhaven National Laboratory*. (2017). https://www.nyserda.ny.gov/-/media/Files/Publications/Research/Electic-Power-Delivery/17-23-Evaluation-of-New-York-Prize.pdf

The BCA cost model used by communities as part of NY Prize is as follows:

$$Costs = f(fixed\ costs, variables\ costs),$$

where fixed costs included design and planning, capital costs, and fixed operation & maintenance (O&M), while variable costs included the cost of natural gas and fuel operation, variable O&M, and environmental damages such as those resulting from carbon emissions.[21]

Likewise, the NY Prize used the following benefits model:

$$Benefits = f(reliability\ benefits, power\ quality\ benefits, avoided\ costs),$$

where estimates of reliability benefits were calculated using the U.S. Department of Energy's Interruption Cost Estimate (ICE) Calculator and represented savings from avoiding the frequency and duration of typical outages.[22] Estimates of power quality benefits were based on reductions in the frequency of voltage sags and swells, while avoided costs included generation cost savings resulting from a reduction in demand for electricity from bulk energy suppliers.[23] According to the NY Prize BCA model, the reduction in demand for electricity from bulk energy suppliers would further lead to the avoidance of damages from emissions such as CO_2, the value of which was modeled using the U.S. Environmental Protection Agency's social cost of carbon (SCC).[24]

It should be noted that while the NY Prize feasibility studies alluded to potential revenue streams in general, they did not directly model cash flows such as the sale of electricity generated as a byproduct of the CHP process. The benefits included in the BCA models instead represent those societal benefits and avoided costs associated with microgrid deployment. As noted by the Brookhaven National Laboratory, including revenues from off-takers within a BCA model would significantly bolster the case for microgrid feasibility.[25]

As will be set forth below, the Study Team chose to analyze projected direct revenue streams to determine the feasibility of the uGrid. This strategy was deployed because direct revenue streams will be what private investors are likely to consider in determining whether to build the microgrid. However, the NY Prize cost-benefit analyses are instructive for the uGrid analysis: they identify additional community and end-user value that would be realized over and above that identified in the uGrid models. As the Brookhaven studies have shown, these values are neither insignificant nor impossible to measure. Analysis for the NY Prize data also provided a

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[21] *Id.*

[22] *Id.* Typical outage frequency and duration for a given community's utility were based on its System Average Interruption Frequency Index (SAIFI) and Customer Average Interruption Duration Index (CAIDI), which are reliability indicators that the New York State Department of Public Service reports for all utilities.

[23] *See* NY Prize Feasibility Study for Village of Rockville Centre. *NYSERDA.* https://www.nyserda.ny.gov/All-Programs/Programs/NY-Prize/Feasibility-Studies

[24] *Id.*

[25] *See supra footnote 20* ("the sale of energy captured from the exhaust heat of (CHP) can greatly supplement the total revenue produced by the microgrid and improve its overall financial viability").

validation of the capital expense estimates used in the uGrid model by showing that the construction costs were comparable.

C. Conceptual Microgrid

For this study and the proposed Cleveland uGrid, the microgrid infrastructure has been broken into the following asset groups:

- Generation resources
- Distribution network
- Microgrid operations and controls

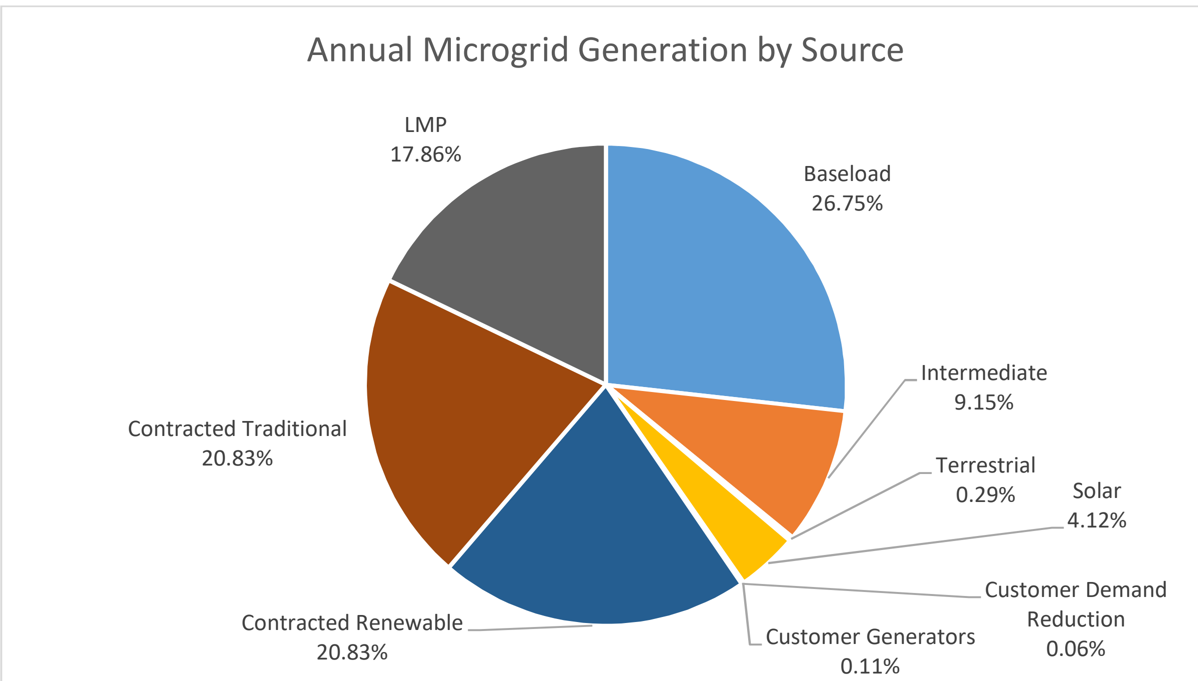
The conceptual microgrid design leverages existing infrastructure in the study area including the proposed Cleveland Thermal CHP plant and the existing CPP distribution system which contains both utility interconnects and distribution substations.

In the model we have assumed that the microgrid will rely principally on purchased power from the Cleveland Thermal CHP and, when not islanded, from external power delivered from the regional grid. The 50 MW size of the microgrid is based on the expected generation capacity of the Cleveland Thermal CHP facility combined with projections of additional, non-critical loads at the customer locations. Other potential power sources would include local solar, wind, and demand response within the microgrid. The chart below shows the breakdown from these various sources. The sources include:

- CHP Power
    - Baseload – generated regardless of CHP steam demand
    - Intermediate – variably generated depending on CHP steam demand
- Grid Power
    - Contracted Traditional – purchased power on the PJM grid using long term contracts
    - Contracted Renewable – purchased renewable power on the PJM grid using long term contracts including Power Purchase Agreements (PPAs)
    - LMP – spot power purchased at Location Marginal Pricing (LMP) on the PJM grid
- Solar from solar PV installations within the microgrid
- Terrestrial Wind from small turbine installations within the microgrid
- Customer Generators – power provided from diesel generators in place at microgrid customer locations for which the microgrid operator pays the customer for capacity, usage, and the ability to dispatch during extremely high LMP pricing events or emergencies
- Customer Demand Reduction – capacity provided by the microgrid operator either automatically or through a manual process reducing the load at a customer site based on LMP pricing or during emergencies

In addition to sources of generation, the microgrid will need power regulation capabilities and short-term back-up power in the form of storage. Storage provides the microgrid with the ability to support frequency and voltage in the transition from normal to island modes as well as the ability to improve power quality while in either normal or island mode.[26] To support these features of the microgrid, the storage solution will need the ability to quickly transition from 'charging' to 'discharging' mode and have the capacity to monitor power quality and inject appropriate electric waveforms onto the grid. In an extreme emergency situation where the microgrid topology may need reconfiguration, the storage units proposed at different locations in the uGrid can provide short duration back-up power until a generation source is connected to that portion of the distribution system.

Figure 3. Proposed Cleveland uGrid Generation by Source



Purchasing the power from the proposed Cleveland Thermal CHP plant is the most cost-effective strategy for obtaining reliable power and will be an important factor in making the uGrid feasible. CHP plants are normally designed to generate thermal energy first, and electricity generated therefrom is typically considered a by-product of the process. This thermal focus makes electricity prices from CHP among the lowest available, especially given natural gas prices available in the summer of 2018.[27] The best alternative to CHP would be for the operator to construct an on-site natural gas combined cycle generation plant. If the microgrid operator had to construct its own generation system to act as the core generation source, this would not only

[26] The Study Team used utility-scale lithium-ion batteries in its cost analysis. However, for purposes of this discussion, they are not included as a physical "source" of power.

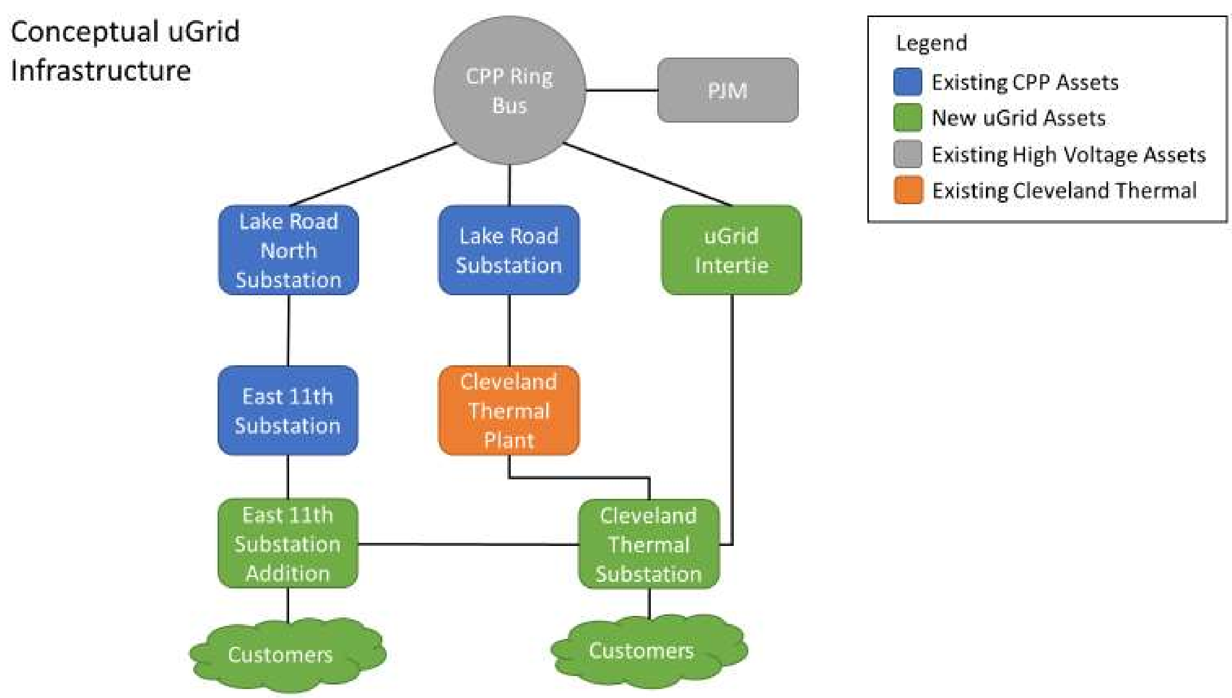
[27] Natural gas was trading at the Dominion South market hub at around $2.25/mmbtu in July 2018 per Natural Gas Intelligence (NGI).

increase the capital expense, but also raise additional concerns about system efficiency, maintenance, and customer requirements. With an estimated construction cost for a new large-scale natural gas-only plant of around $1,500/kW and non-fuel costs at $0.01/kWh,[28] the additional debt burden from the approximately $30 million of additional capital expense plus non-fuel costs would greatly exceed the budgetary pricing received from Cleveland Thermal for the CHP-generated power, before adding in fuel costs.

The distribution system for the microgrid is based on CPP's existing infrastructure as shown in the diagram below. It includes the following elements:

- New primary 50MW intertie to the CPP existing 138KV Ring Bus system
- New Cleveland Thermal CHP facility 11.5kV substation
- Upgrades to the CPP existing E11th Street Substation
- New 11.5kV Battery Systems located at the E11th Street, New CHP, and Intertie locations
- Upgrades and additions to substation feeder and tie cabling
- Additional customer feeder cabling from the E11th Street and New CHP substations

Figure 4. Conceptual Microgrid Block Diagram



[28] From Catalog of CHP Technologies, Section 1. Introduction U.S. Environmental Protection Agency, Combined Heat and Power Partnership, March, 2015 https://www.epa.gov/sites/production/files/2015-07/documents/catalog_of_chp_technologies_section_1._introduction.pdf

The design and cost estimate of the uGrid are based on having 50 customers with an average customer size of approximately 1 MW of total demand spread across three (3) service delivery tiers. Tier 1 would be the highest tier and deliver five-9 power. Tier 2 loads would be serviced based on the availability on generation within the uGrid during an islanding event to keep as much load operating as long as possible. This generation during island mode would come from unused capacity from the CHP base generation due to lower Tier 1 demand, additional generation from the CHP coming from waste steam generation, and other generation sources within the uGrid such as solar or customer back-up generators. Tier 3 loads would be treated as if they were connected to the existing macro-grid meaning that when the uGrid went into island mode, these loads would be immediately turned off. Each customer would segregate their load into each tier, having at least a part of their load be Tier 1 or 2. The microgrid controllers placed at each customer's location would monitor and manage the three Tiers, turning Tier 2 and 3 circuits as appropriate.

This conceptual design provides for maximum resiliency and redundancy minimizing the possibility of power loss at a customer through any single point failure and providing the microgrid operator with the ability to quickly recover from a more catastrophic or wide-spread set of failures. Some examples of these redundancies include:

- <u>Utility Interconnect.</u>
  By having a double-ended connection to the CPP Ring Bus, the conceptual design minimizes the likelihood of loss of normal utility power due to single mode failure of any single interconnect to PJM as well as single point failure within the ring bus and with the microgrid connection to the ring bus.

- <u>Substation.</u>
  If either the Lake Road North substation (which feeds existing E11th Street) or new Intertie substation fails, normal utility power could be routed through the other substation and feed all the load.

- <u>Customer Feeder.</u>
  Should a customer want additional redundancy, the distribution from the substation to the customer can be performed from both the E11th Street and New CHP substations, or from different ends of one of the substations. This eliminates single mode failure of their distribution breaker.

Capital costs from the proposed conceptual design were developed from three estimates provided by Schneider Electric, Eaton, and Middough. These estimates were based on information and drawings provided by CPP as well as a walk-through of the existing substations.

The final element of the microgrid is the control system. The control system includes a variety of components:

- Customer site equipment which monitors and controls customer loads and provide information back to the central control system
- Substation and generator equipment which monitors the substations and generators including the CHP and provide supervisory control signals to the local controls operated by CPP and Cleveland Thermal
- Central control system which includes supervisory controls, operator interface, and historian capabilities
- Fiber optic network to connect all the above components

Capital and operational costs for the control system and network were derived through an RFI performed by Cuyahoga County and based on the conceptual design. The RFI respondents included Siemens, Rockwell Automation, S&C Electric, Schneider Electric, Eaton, OATI, and ABB. The Study team also undertook numerous conversations with various control system manufacturers and integrators as well as site visits to demonstration centers.

D. Business Structure

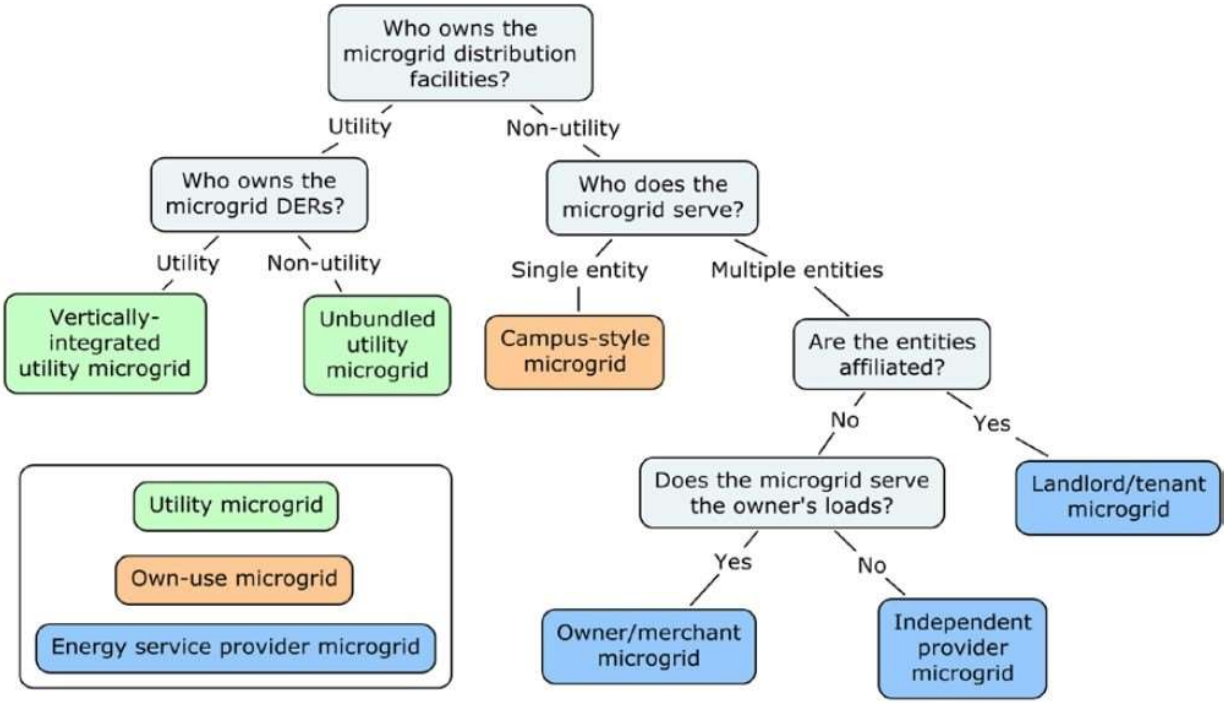
The development of the business structure is highly dependent upon the key business objectives that the stakeholders wish to obtain, and the specific facts involved. Strategies will be controlled by several factors, including the role of the microgrid (e.g., single campus or commercial) regulatory environment, property rights, operating responsibilities and financing arrangements, among other considerations.[29] Brookhaven National Labs developed a decision tree for establishing microgrid business models as shown in Figure 5.

The proposed Cleveland uGrid should be designed to (1) minimize federal and state regulation of the microgrid;[30] (2) develop a mechanism to ensure repayment of debt incurred to construct the microgrid; and (3) accommodate achievement of other non-rate goals. The proposed plan provides that a grid operator would enter into multiple service agreements with power generators, Cleveland Public Power and end users. The operator could be a private, for-profit company, or could be a government body, such as Cuyahoga County, which then subcontracts to a for-profit with expertise to operate. CPP would collect a distribution tariff, just as it does from other rate payers.

[29] R. Lofaro, "Evaluation of New York Prize Stage 1 Feasibility Assessments," Brookhaven National Labs, 2017, [citation]

[30] Although the Ohio Public Utility Commission has not yet set forth regulatory rules for microgrid operations, Cleveland Public Power, as a municipal utility, is not regulated by the PUCO, and has broad discretion in how it might operate a microgrid. *See* Ohio Const. Article XVIII, Section 4. This Constitutional authority has been interpreted broadly, giving a municipality a great deal of freedom over the operation and management of its power distribution services. *See* R.C. § 4905.02 (excluding a municipal utility from the regulatory jurisdiction of the PUCO); *See also* R.C. § 4933.83 (excluding a municipal utility from the reach of the Certified Territory Act). *Cleveland Elec. Illuminating Co.*, 95-458-EL-UNC, 2004 WL 3142703 (F.E.D.A.P.J.P. Dec. 21, 2004) (refusing to "evaluat[e] the prudence of CPP's portfolio management").

Figure 5. Microgrid Business Ownership Typology



Brookhaven National Labs (2017).[31]

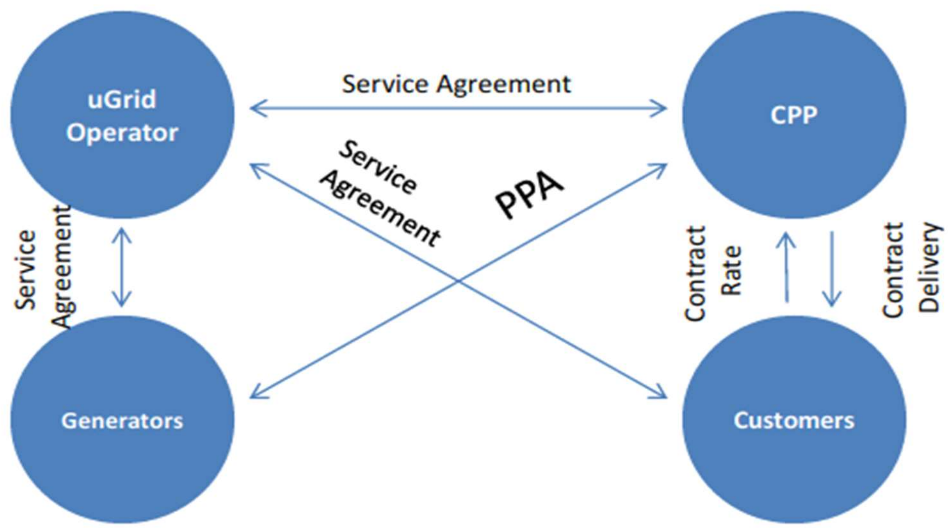
Below is a diagram that outlines one proposed conceptual structure. It consists of the following:

- Generation resources entering into PPA's with CPP to purchase power for the duration of at least the debt service period for the microgrid;
- CPP entering into contracts with microgrid customers for the same or similar term as the PPA's, to provide distribution, microgrid generation and the remaining generation services. There likely would need to be a new "Microgrid Rate Schedule" established by CPP for this project, approved by Cleveland City Council; and
- Microgrid operator entering into service agreements with CPP, the generation resources and the customers, to manage the microgrid.

Roles and responsibilities between the uGrid operator and CPP would need to be established in detail during the RFQ/RFP phase of the potential project and finalized in the service agreement contract between the parties. The service agreement would need to be highly detailed, including, but by no means limited to, items such as sales and marketing, customer service call routing, and fee structures. This level of detail will ensure that both the uGrid operator and CPP can appropriately and accurately account for costs as they evaluate the potential revenue and value of the uGrid.

[31] *Id.*

Figure 6. Possible Business Structure for Downtown Cleveland Microgrid



Some possible structures include:

- Governmental Ownership.
  Subject to further review of the County and City Charters, the County or City (CPP) could serve as microgrid operator. This would require the County or City to contract with a third-party provider to perform the services. The County or City would enter into service contracts with generators, customers and CPP to pass through the costs and to be paid the revenues. Advantages would include that revenues received by the governmental owner would not be taxable, and such revenues (together with other revenues) could be pledged to repay debt issued to construct the microgrid. Disadvantages would include potential liability of governmental entities to customers for microgrid operational problems.

- Customer-Owned For-Profit Third-Party Entity.
  The private enterprise microgrid customers could form a member-owned, for-profit entity. Governmental entities would not be able to own interests in the company because of Ohio law restrictions. This entity would either hire its own employee(s) to operate the microgrid, or contract with a third-party expert. This entity would enter into service contracts with generators, customers, (including government customers) and CPP. Advantages would be a full alignment of customer and microgrid operator interests and potential efficiencies in private sector operations. Disadvantages would be that revenues would be taxable, and it might be more difficult to pledge the operating revenues in a financing deal.

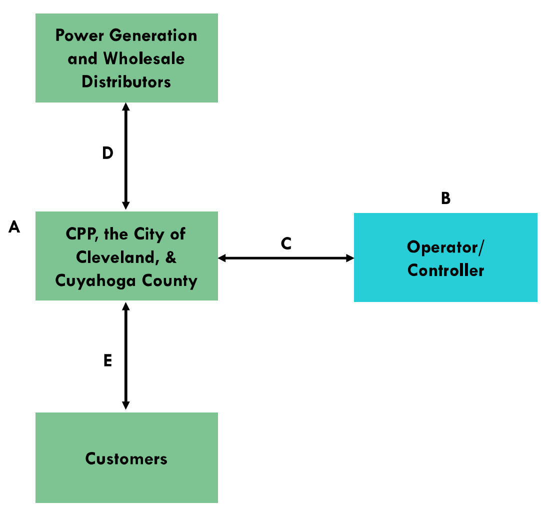
- Independent For-Profit Third-Party Entity.

This structure would involve a wholly independent third party assuming the contractual responsibility of operating the microgrid. This entity would be a large company already engaged in this or a similar business, or a smaller entrepreneurial company seeking to enter the market with experienced management. Advantages and disadvantages would be as set forth above for customer-owned for-profit third-party entity.

The model chosen may be impacted by taxes and sources of public financing. Two potential models are set forth below. In the first, the operator owns the uGrid control system, the construction is financed by a mixture of public and private equity, and the municipal utility owns the distribution system ("CPP-Owned" model) (Figure 7). The potential second model proposes that the operator finance all building, and owns the distribution lines, which it leases to the municipal utility ("Tax Efficient" model) (Figure 8). A comparison of the considerations is set forth in

Table 3 below.

Figure 7. Option 1: CPP-Owned Model

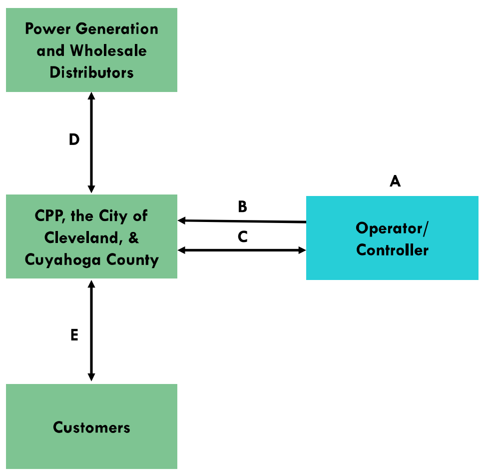


DESCRIPTION

A. The City designs and builds the distribution infrastructure (wires and substations) that makes up the µGrid. The construction is financed with City and County debt. CPP owns the distribution infrastructure.
B. The Operator constructs the µGrid's control system. The control system will be financed with private equity. Additionally, the control system will be owned by the Operator, allowing the operator to take depreciation deductions on the equipment. Ideally the Operator will be a large corporation or investment fund that can insure and indemnify CPP for any system failures.
C. The Operator and CPP enter into a Management Agreement, under which the Operator is obligated to manage and maintain the µGrid and its infrastructure.
D. CPP purchases power from Power Generators and Wholesale Distributors, pursuant to Power Purchase Agreements, to be distributed at retail to customers.
E. CPP distributes power purchased from Power Generators and Wholesale Distributors to its customers, utilizing the µGrid distribution infrastructure.

2

Figure 8. Option 2: Tax Efficient Model



DESCRIPTION

A. The Operator designs and builds both the distribution infrastructure and the control system. The construction is financed with a mix of public debt and private equity. The Operator is the owner of the both the distribution infrastructure and the control system, allowing it to take advantage of asset depreciation on both. Ideally the Operator will be a large corporation or investment fund that can insure and indemnify CPP for any system failures.

B. The Operator leases CPP the right to use the µGrid, under a Long-term lease.

C. The Operator and CPP enter into a Management Agreement, under which the Operator is obligated to manage and maintain the µGrid and its infrastructure.

D. CPP purchases power from Power Generators and Wholesale Distributors, pursuant to Power Purchase Agreements, to be distributed at retail to customers.

E. CPP distributes power purchased from Power Generators and Wholesale Distributors to its customers, utilizing the µGrid network and infrastructure.

3

Table 3. Comparison of CPP-Owned and Tax Efficient Models

	Option 1: CPP-Owned Model	Option 2: Tax Efficient Model
Ownership Structure	• CPP, a municipal entity, owns the distribution infrastructure (wires and substations). • The Operator, a private entity, owns the control system.	• Operator, a private entity, owns the distribution infrastructure and the control system. • CPP leases the right to use the uGrid distribution system.
Capital Structure	• Construction of the distribution infrastructure is entirely financed with public debt. • Construction of the control system is financed with private equity.	• Construction of both the distribution infrastructure and the control system are financed with private equity.
Depreciation Structure	• Depreciation on the distribution infrastructure is lost. • Depreciation on the control system equipment is captured by the Operator.	• Depreciation on the entire uGrid is captured by the Operator.
Regulatory Considerations	• CPP owns all the distribution infrastructure. • CPP is responsible for distributing power, billing, and collecting revenues from customers.	• Operators own and maintain the distribution infrastructure, which it leases to CPP. • CPP is responsible for distributing power, billing, and collecting revenues from customers.

These are only two possible structures – there are many others that may be more attractive to designers, builders and investors depending upon the circumstances. Regardless which model is chosen, there will need to be a contractual relationship between the local distribution utility and the microgrid operating company. The uGrid model developed herein is similar to the "CPP-owned" model: it assumes no benefit from depreciation. It also assumes no income tax and no benefit from subsidized loans.[32]

Other strategies would have to be deployed for microgrids that are within investor-owned utility territories and in front of the meter. In Ohio, such microgrids will fall into the ambit of the Public Utility Commission of Ohio (PUCO). The PUCO intends to review, through its "Power Forward" initiative, Ohio's regulatory schemes in light of microgrid, smart grid and other grid-edge technology development.

III. Economic Feasibility

The Survey Team developed a techno-economic model based on the conceptual design developed in the technical feasibility. The model balances the construction, financing, energy and operational costs against customer revenues less fees paid to the distribution utility.

$$\begin{aligned} &Annual\ Profit \\ &\qquad = Customer\ Revenue - Generation\ Costs - Operational\ Costs \\ &\qquad - CPP\ Fees - Clean\ Energy\ Fund\ Fees - Debt\ Payments \end{aligned}$$

where

$$Customer\ Revenue = f(Energy, Customer\ Rates)$$
$$Generation\ Costs = f(Energy, Contracted\ and\ Marginal\ Electric\ Rates)$$
$$Operation\ Costs = 25\% \times Customer\ Revenue$$
$$CPP\ Fees = \$0.025/kWh \times Energy$$
$$Clean\ Energy\ Fund\ Fees = \$0.002/kWh \times Energy$$
$$Debt\ Payments = f(Construction\ Cost, 30\ year\ term, 5\%\ interest\ rate)$$

Each term in the profit equation was developed based on vendor proposals, utility market analyses and industry knowledge and benchmarks. The Customer Rates were then analyzed to determine a set of costs which yielded break-even profitability over the 30-year operating term.

A. Customer Rates

The customer rate is the most readily available parameter to change in the profit equation and ties directly to other research performed by the project team concerning price premiums customers would be willing to pay for highly resilient power. Since the rate structure has three tiers, we used the following design parameters to develop rates:

- Tier 1 rate should always be the most expensive
- Tier 2 rate should always be between Tiers 1 and 3

[32] The Study Team considered the impact of taxes versus the benefits of depreciation and could not identify any appreciable advantage of one model over the other. Ultimately the builder will have to evaluate its own models based upon its own tax considerations.

- Tier 3 rate should be the least expensive and should approximate current power costs in the microgrid study area.

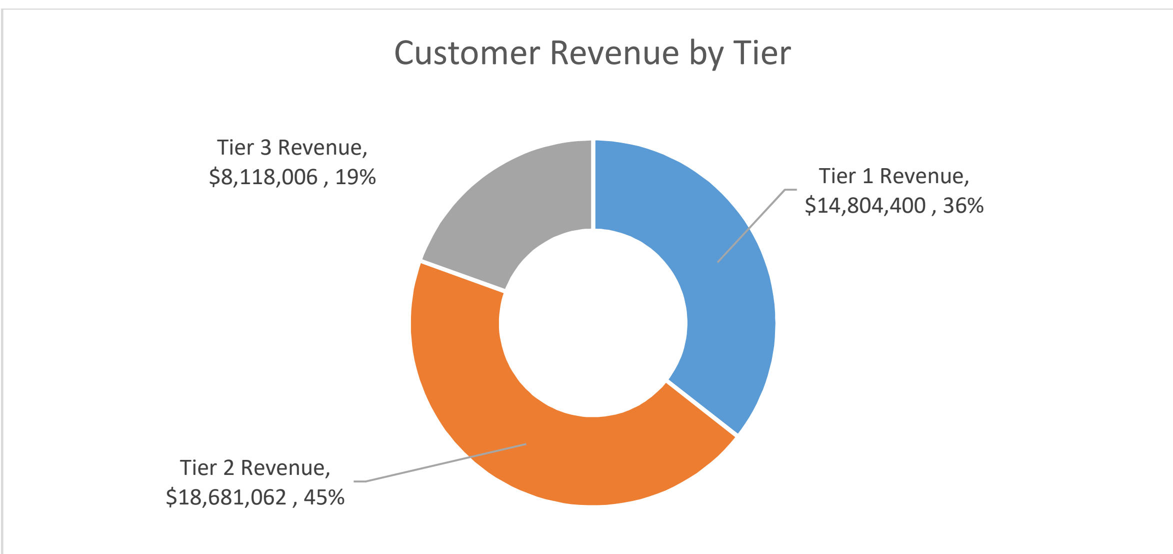
To determine the approximate Tier 3 rate, the study team analyzed the total blended rate for three exemplars using the published rate schedules of CPP and estimates for the variable charge Ecological Adjustment Charge (EAC) component of the rate.[33] The three exemplars are:

- Small Commercial, less than 30 kW Peak Demand, Average Demand 20 kW
- Large Commercial, over 30 kW Peak Demand, Average Demand 100 kW, No kVAR charges, 100% Load Factor
- Industrial, Average Demand 5 MW, No kVAR charges, 100% Load Factor

The resulting blended rates, taking all line items in the bill and looking across a calendar year, range from \$84 to \$118/MWh with an average of \$103/MWh. This average is higher than our base model assumed Tier 3 rate of \$92/MWh.

Since the amount of expected power consumption per Tier is not equal, the impact of adjusting one of the Tier rates will be different for each Tier. This difference is illustrated in the percentage of steady-state annual revenue expected by Tier as shown in Figure 9 below.

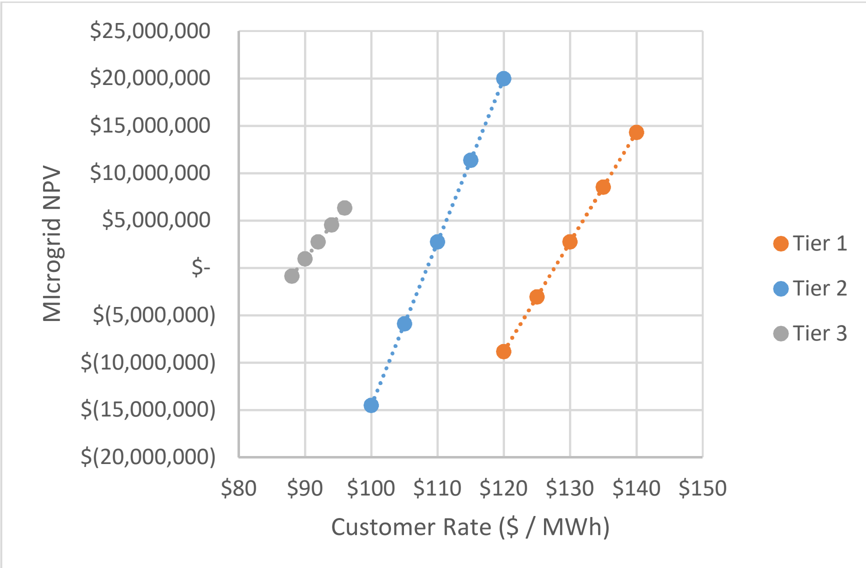
Figure 9. Microgrid Customer Revenue by Tier



A sensitivity analysis of the customer rate structures performed by adjusting one rate at a time and holding the other two rates constant showed that the economic model was most sensitive to changes in the Tier 2 rate. This finding is consistent with the graph above where Tier 2 revenue is the largest revenue source.

[33] Assumed values for the EAC in this analysis were \$0.08 / kWh for Summer and \$0.06 / kWh for Winter

Figure 10. Results of Sensitivity Analysis to Customer Rate



Customer Rate	$ NPV per $/MWh
Tier 2	$1,726,181.62
Tier 1	$1,157,839.57
Tier 3	$897,144.69

B. Successful and Timely Customer Recruitment

A significant portion of the capital expense in constructing and establishing the microgrid is fixed. These expenses include substation additions and upgrades and the central control system and network. Additionally, the microgrid operator may have operational costs including staffing and potentially the need to enter into energy contracts, particularly with the CHP plant, prior to having customer commitments.

To approximate this disparity between revenue and expense, the model assumed that all capital expense, and therefore the associated debt service, started in year 1, while all operational expense including microgrid operational costs as well as energy costs were incurred as energy was sold. Then a 20% per year customer acquisition rate was applied with the first 20% in year 1 as "anchor customers" and achieving full customer load in year 5 and maintaining it through the 30-year operation.

This assumption leads to a negative cash flow in the first 3 years of operation as shown in the table below.

Table 4. Microgrid Customer Acquisition and Cash Flows in First 5 Operational Years

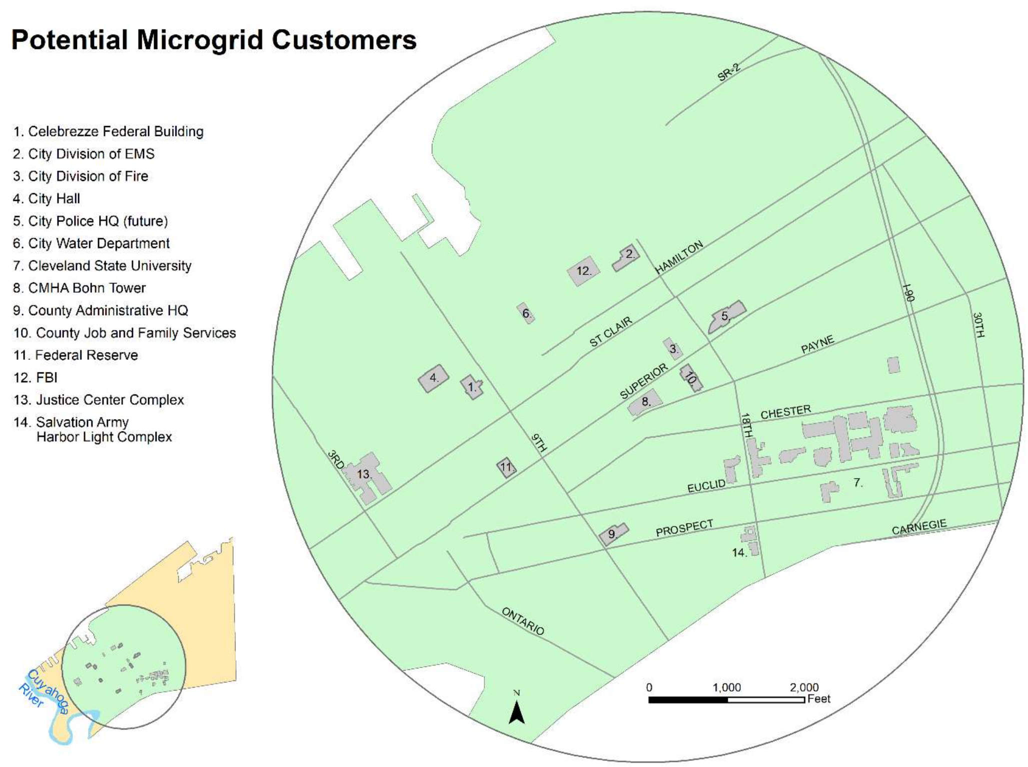
	Year 1	Year 2	Year 3	Year 4	Year 5
Customer Acquisition	20%	40%	60%	80%	100%
Net Cash	$(4,518,864)	$(2,827,656)	$(1,176,366)	$434,128	$2,002,929

There are several ways that the microgrid operator and other stakeholders can mitigate this risk including the following, but these methods will likely have an impact on the cost of capital and potentially customer rates:

- Increasing initial debt to include operating cash for initial years
- Working with the City and County to establish / ensure anchor customers
- Obtaining operational cost assurances from the City and/or County

The Study Team has identified some of these potential customers listed below, but until pricing and service levels are finalized and contracted, it is impossible to confirm their willingness or ability to participate. In addition, as set forth in the companion paper examining the potential economic impact benefits of the uGrid, a significant fraction of the microgrid power may need to be reserved for new commercial development in order to maximize regional economic impact.

Figure 11. Map of Existing Potential Microgrid Customers



C. Availability of Long Term, Competitive Electrical Power and Natural Gas Prices

Over the duration of the microgrid, electricity prices are expected to increase. The model uses an annual growth rate of 2% for electricity purchased in the real-time market (LMP electricity) and uses an annual growth rate of 1% for contracted electricity, including both renewable and traditional electricity. These assumptions are aligned with the Department of Energy annual growth projections for electricity generation costs.[34]

However, the model also assumes that other sources of electricity for the microgrid will remain fixed based on long term contracting with the generators, primarily Cleveland Thermal, but also renewables providers within the microgrid territory. This assumption provides Cleveland Thermal with a known, long-term revenue stream. The likely contract structure between the microgrid operator and Cleveland Thermal will be adjustable based on the cost of natural gas, but these prices are not expected to rise over the next 20 years at a rate significantly more than inflation.[35]

For renewable energy generation within the microgrid, long-term power purchase agreements are the standard contracting mechanism, and these commonly include fixed rates with little or no escalation. Holding prices from renewable sources constant is, a result, reasonable. Due to the small percentage of overall renewable generation included in the model, variable or escalating prices will have a negligible effect on the model. Likewise, the pricing for demand response and customer generation is assumed to be constant. These prices would be instantiated in the customer tariff agreement with CPP and therefore would be difficult and unlikely to be renegotiated.

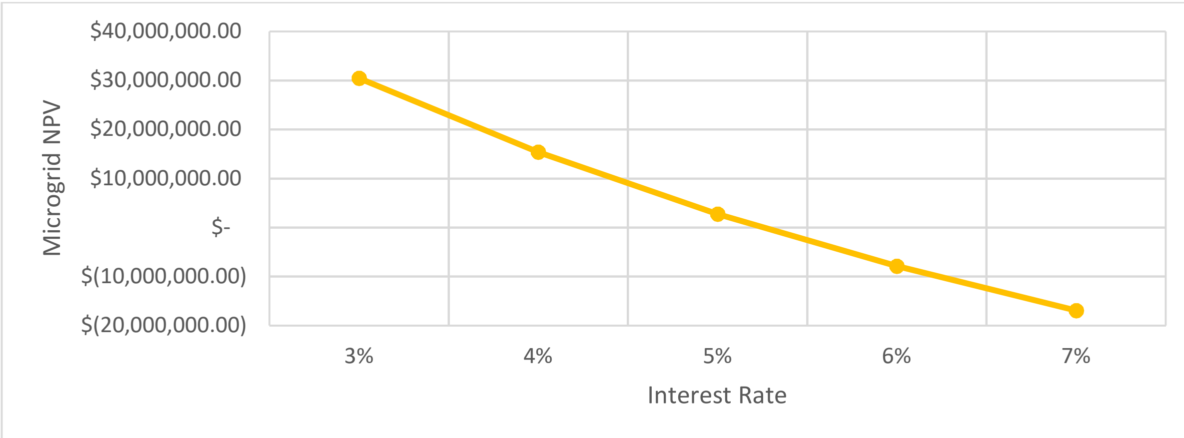
The cumulative effect of these pricing assumptions is that the projected blended energy (i.e. generation) cost for the model starts at $44.84/MWh and experiences an average annual growth rate of 0.85% over the term. This is comparable to the best prices currently available for wholesale power from within the PJM footprint.

D. Cost of Capital / Interest Rates

The cost of capital and interest rate for the model is assumed at 5%. This number is used in the calculation of the debt service costs as well as the net present value calculations on the cash flows. The capital investments, as listed in section II(B), consist of additions and enhancements to the distribution system, the microgrid control system, and the engineering and technical services to deploy the microgrid. As shown in Figure 12, the NPV is highly sensitive to changes in the interest rate losing approximately $15 million in NPV per rate point.

[34] Annual Energy Outlook 2018, Electricity Prices by Service Category Generation (Case Reference case), U.S. Energy Information Administration
[35] *Id*.

Figure 12. Results of Sensitivity Analysis to Interest Rate



This sensitivity creates opportunities for the stakeholders in the microgrid to assist in the economic viability of the project. First, the County and City can potentially be involved in the raising of the initial capital thereby lowering the interest rate. A quick survey of long term municipal bonds in the state of Ohio shows a yield to maturity spread of 2.013% to 4.173%.[36] These rates indicate that assistance from the County and/or City could potentially reduce the interest rate that the microgrid operator would obtain for the capital expense debt. Secondly, the importance on cost of capital creates a distinction in the selection of a microgrid operator. Potential operators who have access to lower cost capital will be able to provide more competitive rates while ensuring their rate of return.

E. Distribution Costs from the Municipal Utility

The municipal utility, Cleveland Public Power (CPP), plays an integral role in the proposed microgrid. CPP provides not only the regulatory capability to create the microgrid, but will also be responsible for customer management including:

- Meter reading
- Billing and invoice management
- Tariff approval and maintenance

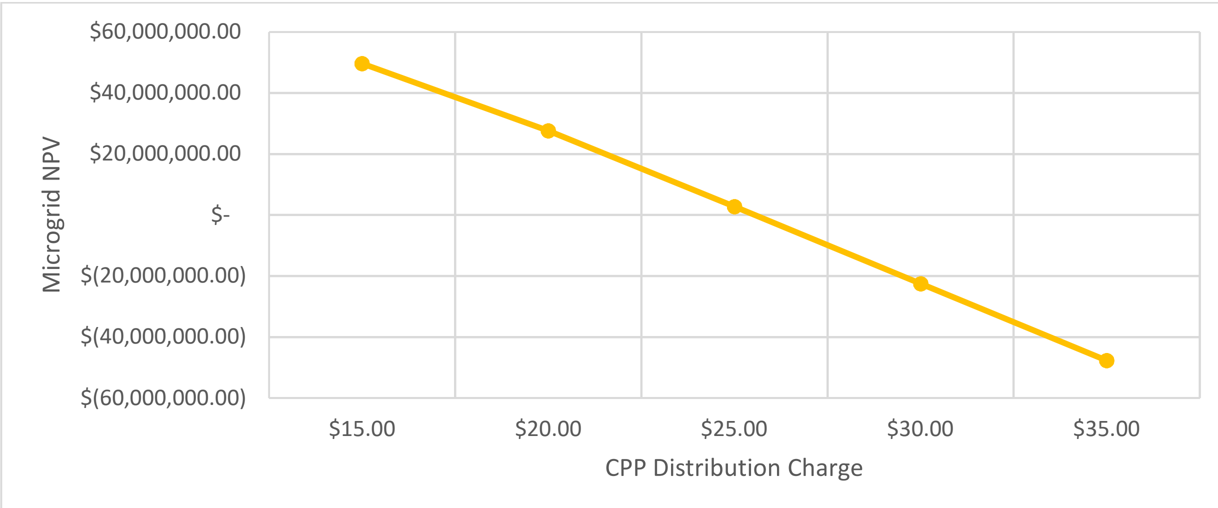
CPP owns and operates the interconnection to the PJM grid and is responsible for all the regulatory and operational responsibilities that entails. CPP also owns the distribution network for the transmission of electricity to the customers, and they must manage and maintain this infrastructure.

Therefore, the model has been developed to include a fee for CPP. This fee is based on a distribution charge of $25/MWh for all electricity delivered to uGrid customers regardless of

[36] Based on 11 issued municipal bonds in Ohio with maturity dates after 2040.

generation source. Since this fee must be subtracted from the rate that would be otherwise collected by the microgrid operator, it is not surprising that the model is highly sensitive to amount charged by CPP, as shown in Figure 13. A charge of $5/MWh more by CPP results in a reduction of $25 million of NPV.

Figure 13. Results of Sensitivity Analysis to CPP Distribution Costs



Although the Study Team undertook preliminary conversations with CPP concerning this fee, there was no determination that a $25/MWh fee would be acceptable to CPP and fit into their delivery cost structure. However, in reviewing the published rates for CPP, this charge does appear to be in line with existing CPP rates and charges.[37] The fee will need continued discussion and finalization should the uGrid development move forward.

IV. Other Discussion Topics

The Study Team identified other factors that could provide benefits to the various stakeholders in a microgrid beyond the direct cost/benefit model analysis set forth herein and that could be monetized by the microgrid operator or other stakeholder to improve the financial performance of the uGrid. Some of those factors are set forth below.

A. Indirect Community Benefits

There are many indirect benefits from a microgrid to the community, ranging from emergency power services to clean air to economic development. Indeed, the culture of innovation and technology advancement is likely to significantly enhance economic development opportunities for the region. The Brookhaven study sets forth how some of these can be put into a cost benefit

[37] See CPP rate schedules available at http://www.cpp.org/rs.html. CPP distribution charges also include demand charges, which are set based upon end-user peak demand and upon how that demand coincides with grid peak demand.

analysis for the community and is discussed in section II(B) above. There are, however, other indirect benefits that could be more readily monetized by the grid operator. The National Renewable Energy Laboratory, for instance, examined the value that energy storage has in reducing demand charges which are utility charges that are typically based on the peak amount of energy that a customer uses in a specified time interval. Demand charges are designed to enable the utility to recover costs associated with having to build distribution capacity that is idle except for during peak demand periods. The end user's demand charge is usually set by a formula that considers, among other things, how that end user's peak demand coincides with the grid's peak demand. An end user whose own peak coincides with grid peak pays a higher demand charge.

Demand charges are not trivial. NREL determined that 25% of commercial customers pay demand charges greater than $0.015/kWh.[38] A microgrid can reduce this cost substantially. The microgrid operator can manage coincident peak contribution during peak grid times, such as hot summer afternoons. Likewise, a microgrid operator could manage peak load contribution for PJM capacity charges and could even sell power back to the grid during peak load periods. These actions would in turn allow the microgrid operator to pass on the savings to the microgrid customers.

B. District Energy

District Energy provides additional value to the community and opportunity to the grid operator. Cleveland Thermal owns a district energy system in downtown Cleveland that provides both steam and cooling, and the system has capacity to grow. A district energy system is complimentary to the microgrid: together they provide opportunities for system efficiencies that could reduce costs and improve reliability. The Combined Heat and Power system is the anchor source of generation for both thermal and electrical loads.

Steam generated from a Combined Heat and Power system would be able to provide more than just heat and byproduct electricity. In the summertime, when heat loads are minimal, the thermal energy from the CHP plant could be recovered to generate chilled water through a process known as absorption chilling. Commercial and industrial settings where chilled water could be utilized for cooling applications include data centers, food processing, cold storage warehouses, office buildings, hospitals and for process cooling in manufacturing. Figure 14 shows a high-level configuration for this sort of co-generation (also known as tri-generation) where electricity, heat, and cooling are products of a natural-gas-fed CHP plant.[39]

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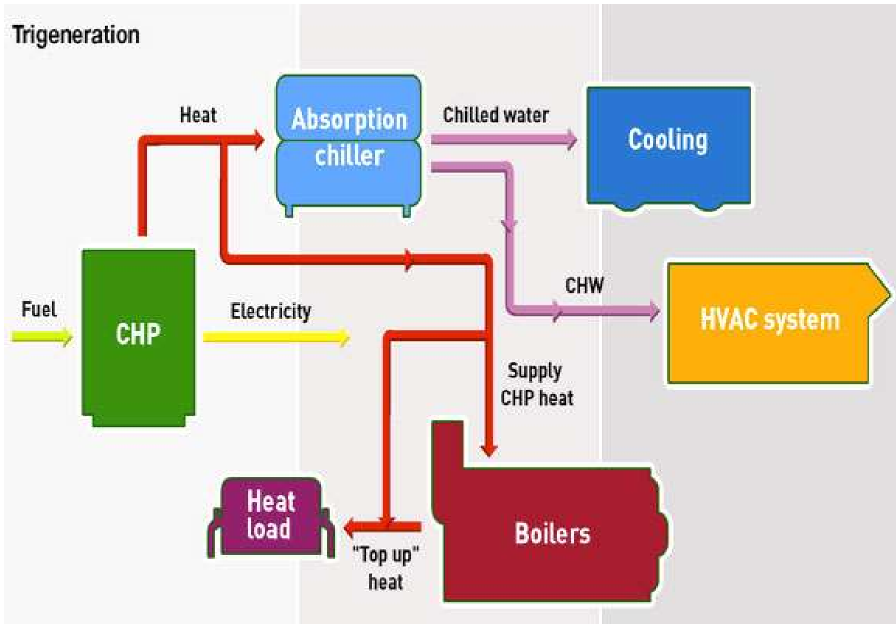
[38] *See* J. McLaren et al, "Identifying Potential Markets for Behind the Meter Battery Energy Storage: A Survey of the U.S. Demand Charges." National Renewable Energy Laboratory (2017) https://www.nrel.gov/docs/fy17osti/68963.pdf See also: E. Wood, "Wondering if Energy Storage Can Reduce Your Demand Charges," Microgrid Knowledge, August 24, 2017, found at: https://microgridknowledge.com/demand-charges-energy-storage/

[39] Wright, I. (2016). "Could Cogeneration Become the Norm in US Factories?" https://www.engineering.com/AdvancedManufacturing/ArticleID/13191/Could-Cogeneration-Become-the-Norm-in-US-Factories.aspx

Figure 14. Simultaneous Production of Three Sources of Usable Energy



CleanTechOps (2016).[40]

Figure 14 illustrates how cooling can be achieved through an absorption chiller, one of the two main technologies for making chilled water.[41] Absorption chillers work with two fluids: a refrigerant and an absorbent. One common refrigerant-absorbent pair is water-lithium bromide. In this scenario, water under very low pressure near vacuum conditions has a low boiling point (around 40° F). When this combination is heated by steam or hot water, the absorption fluid is evaporated, removing heat from the chilled water.[42] A heat source such as steam, exhaust gas, or hot water is used to regenerate the absorption solution.[43]

Chillers in general can be installed on-site or off-site. An off-site installation can be made through a public utility with a central chilled water plant where cooling is distributed through a chilled water network. This option could offer substantial savings for companies compared to the on-site installation of chillers due to the avoided capital costs. With the burden of upfront investment shifted to the utility, customers would pay only for the cooling that they needed.

[40] https://www.cleantechloops.com/what-is-trigeneration/

[41] The other main technology, a steam turbine-driven centrifugal chiller, is similar to an absorption chiller but instead of a heat-driven thermal compressor system uses a mechanical compressor to move refrigerant around the system. *See* "Absorption Chillers for CHP Systems." *U.S. Department of Energy*. (2017). https://www.energy.gov/sites/prod/files/2017/06/f35/CHP-Absorption%20Chiller-compliant.pdf

[42] "How does an absorption chiller work?" *Goldman Energy*. (n.d.). http://goldman.com.au/energy/company-news/how-does-an-absorption-chiller-work/

[43] *Id.*

Table 5 shows the hypothetical 20-year operating cost of cooling with on-site versus off-site district capacity for a typical data center.[44]

Table 5. Life Cycle Comparison of On-Site vs. District Energy Cooling

	20-Year Operating Cost of Cooling
On-Site Energy Plant (Assumed Electrical Load & Cooling Capacity for Chilled Water System: 2.989 MW/850 Tons)	**$19,584,925**
District Energy (Assumed Electrical Load & Cooling Capacity for Chilled Water System: 1.758 MW/500 Tons)	**$13,816,919**
Operating Savings with District Energy:	**$5,768,006**
Percent Savings with District Energy:	**29.45%**

District Energy also enables companies to be more conservative in their growth planning. Companies do not have to overbuild to support future growth, and they do not have excess capacity in the event of business slowdowns. The same sort of companies that are likely to be attracted to a microgrid will also be attracted to district energy, especially chilled water.

V. Conclusion

Microgrids have been found to be cost-effective based upon indirect value to the community, providing emergency power, clean energy and economic development. The proposed Cleveland uGrid will offer these advantages as well. However, the uGrid will require a cost model that will attract investors, likely without being able to monetize such indirect value.

The cost model developed herein suggests that investors may be interested in building a microgrid in downtown Cleveland. It appears that a microgrid could be built that offers end users 99.999% uptime service for around $0.13/kWh, while retaining a 5% return on capital investment plus a 3% return on investment. Whether an energy company would be willing to build and operate the uGrid under these sorts of conditions will likely depend upon how much risk can be reduced or eliminated. It will also depend upon how much Cleveland Public Power will need to recover its costs for the distribution system and billing support.

The proposed model is just one strategy for how a microgrid could be designed and built. Industry experts who examine this opportunity will likely have alternative strategies that they prefer. Further, the cost model presented herein should be examined in conjunction with the Study Group's companion reports on market penetration, economic development, and the value of resiliency.

[44] Based upon Cleveland Thermal estimates.